Fisheries Survey of the Limnetic Zone of Sullivan Lake, Washington, Using Hydroacoustics and Gill Nets, September 2003.

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*Abstract.—*We conducted a fisheries survey of the limnetic zone of Sullivan Lake, Pend Oreille County, Washington during September of 2004. The study represented one of several efforts by WDFW, the Kalispel Tribe, the U.S. Forest Service, and Eastern Washington University (EWU) to better understand the physical and biological processes affecting the status, life history, and ecological interactions of various aquatic species in Sullivan Lake. The objectives of this study were to evaluate the species composition, depth distribution, density, and abundance of fishes in the limnetic zone. We conducted a gill net survey between 23-26 September, 2003 comprised of 51 overnight gill net sets and a hydroacoustic survey that included 27 transects on 23 September. Kokanee and cutthroat trout were the dominant fish species captured in limnetic gill nets, comprising 77% and 12% of the relative abundance, respectively. Vertical distribution of acoustically detected fish was highest between 12 and 20 m depth, with relatively few fish detections below 30 m. Mean density of all acoustically detected fish (30-800 mm) was 7 fish per 10,000 m^3, or 409 fish per hectare. The abundance of kokanee age 1-3 was 67,000 (120 kokanee per hectare), with approximately 10,000 age-3 kokanee. Length-at-age and relative weight for all kokanee, and relative weight for cutthroat trout over 300 mm were below the national average, indicating that food resources may be limiting fish production. This result was consistent with the EWU analysis that showed oligotrophic conditions and a zooplankton community that had the characteristics of size selectivity and heavy predation by zooplanktivorous fishes. This study should provide fishery managers the necessary information to make informed decisions, especially when combined with the results of other ongoing research on Sullivan Lake.

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Acknowledgements

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Introduction

A naturally reproducing kokanee (*Oncorhynchus nerka*) population currently occupies Sullivan Lake in Pend Oreille County, WA. The population was likely established from hatchery stocking. The first documented stocking of kokanee in Washington State was in Sullivan Lake in 1904 when the U.S. Bureau of Fisheries planted 10,000 fry of unknown origin (Crawford 1979). However, after examination of U.S. Fish Commission stocking records, Nine (*in prep.*) concluded that the 1904 plant of "landlocked salmon" were Atlantic salmon *Salmo salar* and the first plant of kokanee in Sullivan Lake was in 1913. Sullivan Lake was planted with kokanee on numerous occasions between 1920 and 1945 (WDFW, unpublished data; Nine *in prep.*); however, there were only two plants after 1945. The first occurred in 1976 when the Washington Department of Game planted 197,960 Lake Whatcom stock kokanee at 1,800 to the pound (WDFW, unpublished data). The Washington Department of Fish and Wildlife (WDFW) planted 43,320 Sullivan Lake origin fry in May 2003 (WDFW, unpublished data). The fry were offspring of spawning kokanee collected from Harvey Creek, a tributary that flows into the southern end of Sullivan Lake in 2002 (McLellan 2003). Based on genetic data, the current population (2003) is closely related to Lake Whatcom stock (Loxterman and Young 2003; Young 2004), suggesting that it was derived from stocking of Lake Whatcom origin fish.

At least a portion of the kokanee from Sullivan Lake spawn in Harvey Creek between the middle of October and late December and spawning was limited to a ~600 m reach just upstream from the lake-stream interface (McLellan 2003 and 2005). Sullivan Lake is drawn down approximately 6.10 m each fall, beginning on October 1, from its full pool elevation of 788.82 m above mean sea level (msl) exposing approximately 700 m of stream (P. Buckley, Pend Oreille PUD, personal communication). All of the kokanee spawning in Harvey Creek occurred in the stretch of the stream that was exposed after the drawdown (McLellan 2003). Trapping operations on Harvey Creek in 2002 revealed approximately 3,500 spawning adults (McLellan 2003).

The kokanee population in Sullivan Lake is self-sustaining through natural reproduction, whereas populations in many other lakes throughout the state require supplementation through stocking to maintain popular sport fisheries. The majority of the fish used in WDFW's statewide kokanee program are Lake Whatcom stock and they are provided by two WDFW hatcheries located on the lake, near Bellingham, WA (Parametrix 2003). Due to a proposal to establish passage for anadromous salmon to the Middle Fork Nooksack River upstream of a water diversion that connects to Lake Whatcom, the use of that stock may be in jeopardy because it will no longer meet disease policy criteria. Thus, WDFW has begun looking for other potential sources of kokanee eggs. The Sullivan Lake kokanee population that spawns in Harvey Creek was identified as a potential source of surplus eggs to supply part or all of the Region 1 demand. After completion of the Lake Whatcom replacement feasibility study it was evident that more information was needed regarding the standing stock of kokanee in Sullivan Lake.

In addition to interest in Sullivan Lake's kokanee population as an alternate brood source, there was interest in the lake's standing stock and carrying capacity and the potential to enhance the sport fishery. Local groups were particularly interested in establishing a net pen program for rearing and releasing trout, similar to other successful programs in eastern Washington lakes and reservoirs. Additional studies were planned including a Colville National Forest funded fishery and limnology project to be conducted on Sullivan Lake in 2003 by Eastern Washington University. The objectives of the EWU project were to assess the water quality, primary and secondary production, and fish populations in order to understand factors that may limit fish production (Nine *in prep.*). To compliment this study, and provide additional information on the abundance and distribution of the kokanee population, the WDFW implemented a hydroacoustic and gill net survey for September of 2003.

Hydroacoustics uses sound impulses transmitted through water to determine fish size, depth, and population density (Traynor and Ehrenberg 1979; Brandt 1996; Cryer 1996). Abundance and distribution can then be determined by expanding results from individual transects to the entire system (Thorne 1979; Levy et al. 1991; Beauchamp et al. 1997). Hydroacoustics is most effective for suspended limnetic species, such as kokanee, when surveyed with a vertically oriented transducer. However, recent advances in technology using a horizontally oriented transducer allows for fish detection within 1.5 m of the surface (Yule 2000).

Hydroacoustics cannot determine species composition; therefore, alternative methods must complement a hydroacoustic survey. Common methods for verifying acoustic targets include trawling, purse seining, and gill netting (Parkinson et al. 1994; Bean et al. 1996; Yule 2000). Homogeny in species composition and length distribution results in increased confidence in hydroacoustic estimates.

Study Area

Sullivan Lake is located in Pend Oreille County, WA at an elevation of 788 m above mean sea level. The surface area of the lake at full pool elevation is 558.9 hectares. The mean and maximum depths are 58.8 m and 101.2 m, respectively. Sullivan Lake has a volume of 32,853 hectare-m, a drainage area of 132.6 km^2, and a shoreline length of 14.3 km (WDOE 1997). Sullivan Lake has three tributaries: Hall, Noisy and Harvey Creeks. Hall and Noisy Creeks are small (1^{st} and 2^{nd} order), intermittent streams that enter the lake on the northeast and southeast sides, respectively. Harvey Creek (3^{rd} order) is the main tributary to Sullivan Lake and it enters the lake at its south end.

There is a dam at the outlet of Sullivan Lake, which is owned and operated by Pend Oreille Public Utility District (POPUD). The original log crib dam, constructed in 1910,was reconstructed in its current form in 1922 raising the lake 12.2 m from its original elevation (Bamonte and Bamonte 1996). The current lake operation is a drawdown of approximately 6.10 m each fall, beginning on October 1, and the lake refills in the spring with the water from the spring runoff (P. Buckley, POPUD, personal communication).

Most of the property surrounding the lake is Colville National Forest, thus there is little residential development along the lake. There are developed U.S. Forest Service campgrounds and improved boat launches at both the north and south ends of the lake.

The Washington Department of Ecology (WDOE 1997) and Nine (*in prep.*) classified Sullivan Lake as oligotrophic due to the low concentrations of Total Phosphorus and Cholorphyll *a*, and the high Secchi disk depth values. Oligotrophic lakes generally have low production of algae and zooplankton and high water clarity (Horne and Goldman 1994). Aquatic macrophyte densities were low in Sullivan Lake (WDOE 1997). Native fish species known to occupy Sullivan Lake include pygmy whitefish (*Prosopium coulteri*), mountain whitefish (*P. williamsoni*), longnose suckers (*Catostomus catostomus*), redside shiners (*Richardsonius balteatus*), sculpins (*Cottus* spp.), and westslope cutthroat trout (*O. clarki lewisi*) (Washington Water Power, unpublished data; WDFW, unpublished data; Mongillo and Hallock 1995; Nine *in prep.*). Introduced fish species previously collected in Sullivan Lake include kokanee, brown trout (*S. trutta*), rainbow trout (*O. mykiss*), burbot (*Lota lota*), and tench (*Tinca tinca*) (Washington Water Power, unpublished data; WDFW, unpublished data; Mongillo and Hallock 1995; Bonar et al. 1997; Nine *in prep.*).

The Sullivan Lake fishery is currently managed under WDFW's general statewide rules, so the lake is open to fishing year round. The bag limits for trout/kokanee, whitefish, and burbot are 5, 15, and 5 fish, respectively. There are no size restrictions for those species. Sullivan Lake has been stocked with several species of trout and salmon since the early 1900's. Species planted included brown trout, Atlantic salmon, Yellowstone cutthroat (*O. clarki bouveri*), eastern brook trout (*Salvelinus fontinalis*), kokanee, westslope cutthroat trout, and rainbow trout (WDFW, unpublished data; Nine in prep.). The majority of the fish planted were cutthroat trout, presumably the westslope subspecies, and rainbow trout (WDFW, unpublished data). As of 2003, the lake does not receive any regular fish stocking.

Methods

Hydroacoustic Surveys

Sullivan Lake was surveyed on 23 September 2003, with an HTI model 241 echosounder with two 200 kHz transducers; a 15° split-beam transducer in vertical orientation and a 6° x 10° elliptical split-beam transducer in horizontal orientation. The transducers were clamped to a pole and mounted to the starboard side of 6.7 m vessel 1 m below the surface. Data were logged directly into a computer and unprocessed echoes were backed up using digital audiotapes. A pulse repetition rate of 3 pings per second was multiplexed between the transducers at a pulse width of 1.25 ms and a 10 kHz pulse width chirp. The horizontal transducer was offset by 7° and sampled fish targets from 1.5- to 8 m below the surface. Data within 10 m of the horizontal transducer and 8 m of the vertical transducer were excluded from analysis due to the narrow beam width reducing the ability to detect fish and potential boat avoidance by fish in the near field (Mous and Kemper 1996; Yule 2000).

Transects were conducted across the limnetic zone of Sullivan Lake by navigating from predetermined global positioning system (GPS) waypoints (Figure 1). Transects were conducted perpendicular to the long axis of the lake and at least 200 m separated the midpoints. The survey began approximately 90 minutes after sunset (2010), on 23 September, and was completed well before sunrise at 0130 on 24 September. Transect lengths ranged from 689-1037 m (mean 884) for a total survey distance of 23.9 km; and boat speed averaged 6.1 km / hr. A GPS logged the latitude and longitudes into the data files and transect distances were calculated using Terrain Navigator software version 4.05 (Maptech 1999).

A series of acoustic echoes were considered a fish if tracked for at least 3 consecutive pings, within 0.3 m/ping, a maximum velocity of 5 ms/ping, and target strengths between –55 and –27.7 dB (approximately 30-800 mm). Target strengths were converted to fish lengths using a formula generated by Love (1971, 1977), where TL was the fish total length (mm) and TS (dB) was the mean target strength of each tracked fish.

$$TL = [2252.1*[EXP(0.1204*TS)]$$

Hydroacoustic fish density.—Density (fish/10,000 m^3) was calculated for each transect and transect densities were averaged together for a lake-wide estimate of fish density. For each transect, individual tracked fish were verified as real within the post-processing software Echoscape 2.11 (HTI 2002). Raw fish counts were adjusted to the effective beam width within each depth strata by the equation:

$$F_1 = F_0 \bullet \left[1 - \left(\frac{EBW}{NBW}\right)\right]$$

where F_1 was the adjusted fish count, F_0 was the original fish count, EBW was the effective beam width for that stratum and NBW was the nominal beam width for the transducer. Density was calculated by dividing the adjusted fish count by the total swept volume for each transect. Swept volume (V) was calculated as:

$$V = ½ * b * h * l$$

where l was the distance (m) of the transect, h was the distance (m) from the transducer to the end of the stratum (mean bottom depth), and b was the beam diameter calculated by:

$$b = 2R\tan\left(\frac{NBW}{2}\right)$$

where R is the range (m) to the end of the stratum (mean bottom depth). Swept volume was adjusted by subtracting the un-surveyed near-field volume (0-8 m vertical transducer; 0-10 m horizontal transducer) from the total volume.

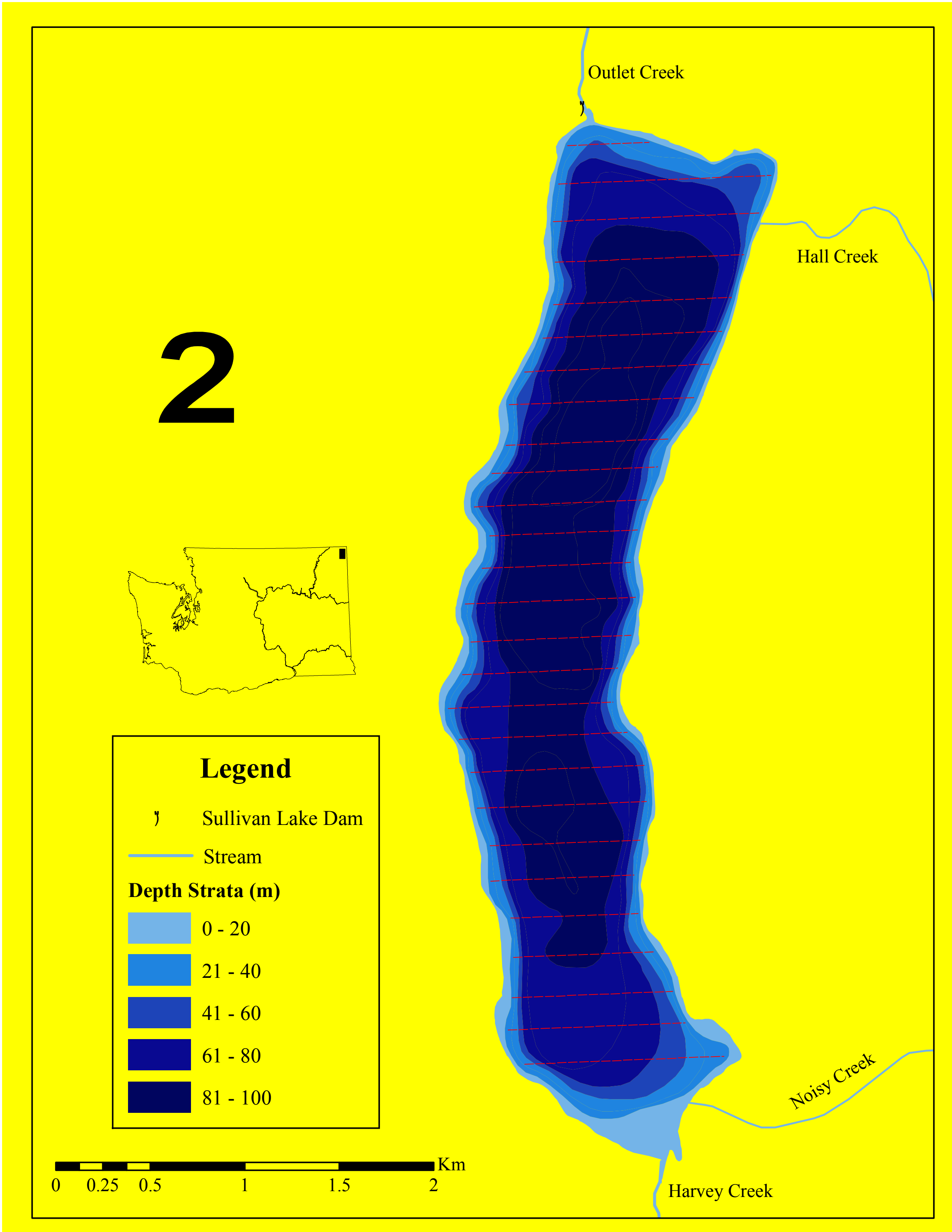

Figure 1. Bathymetric map of Sullivan Lake, WA. Dashed red lines indicate hydroacoustics survey transects completed in September of 2003.

Gill Net Survey

Limnetic gill net surveys were used to provide species verification, depth distributions, and length frequencies of acoustic targets larger than 100 mm. Gill nets were set the night of the acoustic survey (23 September), and for two nights following the survey (24 and 25 September), with various effort allocated each night targeting randomly selected net sites. Vertical gill nets were 2.6 m wide and 46 m deep and had one mesh size throughout (25, 38, 51, 64, 76, 89, or 102 mm stretch monofilament). Horizontal nets were 2.6 m deep and 46 m long with seven panels (25, 38, 51, 64, 76, 89, or 102 mm stretch monofilament) that were each 6.5 m long. Terrain Navigator (Maptech 1999) software was used to spatially segregate the limnetic sampling sites by placing points 200 m apart along the predetermined hydroacoustic survey transects. This method provided uniform coverage of the offshore zone and a GPS waypoint for navigation and net deployment. Netting locations were then randomly selected using Microsoft® Excel 97 SR-1. Our goal was to sample over 40 % of the potential limnetic sampling sites that were deep enough (at least 20 m) and far enough from shore (~ 200 m) to be considered in the limnetic zone.

Age, Size, and Relative Weight

All fish captured in gill nets were measured to the nearest mm and weighed to the nearest gram. Several scales were taken from just posterior to the dorsal fin and above the lateral line. Scale samples were mounted on adhesive data cards and pressed onto acetate slides using a Carver laboratory press (Fletcher 1993). Fish age was determined by the number of annuli and no back calculations were made. Relative weights were calculated using standard formulas for all cutthroat trout and kokanee captured in both nearshore and offshore gill net surveys (Anderson and Newman 1996; Hyatt and Hubert 2000).

Limnetic Fish Abundance

Mean fish density was multiplied by lake volume to estimate abundance. Two standard errors were used to estimate the 95 % confidence interval of the acoustic abundance estimate. Size-specific abundance estimates were determined by applying the percent frequency of each size class from the down-looking transducer to the total abundance estimate. We applied the length frequency from the vertical transducer to the horizontal acoustic targets because fish target echoes in horizontal aspect do not relate to fish length as they do in vertical aspect (Kubecka 1994; Yule 2000). The assumption that fish species composition and size distribution was the same from 1- to 8 m (horizontal acoustics) and from 8 m to lake bottom was validated with netting data. The coefficient of variation from the total abundance estimate was applied to size-specific abundance estimates. Species-specific abundance estimates were calculated by multiplying the species composition from the gill net survey by the acoustic abundance estimates. We did not capture fish less than 100 mm long in the offshore zone so no estimate was made for acoustic targets corresponding to this size class.

Results

Hydroacoustic Density and Distribution

Lake wide mean fish density was 7.0 (± 2 SE; 4.9) fish per 10,000 m^3. There was no significant difference in the mean density of fish from the horizontal transducer (0-8 m) (6.7 ± 8.6) and the vertical transducer (8 m – lake bottom) (7.2 ± 2.0)(t-test, df 26, p= 0.89); however, the horizontal transducer mean density was heavily influenced by high densities of fish in transects 1 and 2 (at the North end of the lake) (Figure 2). Fish density from the vertical transducer was more consistent throughout the lake with increases at both the North and South end of the lake (Figure 2).

Relatively few fish were distributed deeper than 30 m, with the highest densities occurring from 16-24 m (Figure 3).

Gill Net Surveys

We sampled 41% (51 of 125) of the potential limnetic sites with a combination of vertical and horizontal gill nets. Limnetic nets caught 66 fish during three nights and kokanee dominated the species composition (77%), with cutthroat trout comprising a distant second with 12% of the species composition (Table 1). Vertical gill nets accounted for 57% of the total catch, with a catch-per-unit-effort (CPUE) of 1.00 fish per net-night (Table 2). The floating horizontal net had the highest CPUE (2.75 fish per net-night), capturing 11 fish in 4 net sets (Table 2). Three suspended horizontal nets failed to capture any fish when set more than 30 m below the surface (Table 2).

Fish were most commonly captured in the upper 32 m of the water column, with the majority of fish being captured between 0-16 m (Figure 4). Kokanee were captured in similar numbers throughout the upper 24 m of the water column, whereas cutthroat trout were only captured in the upper 16 m and were 3 times more likely to be captured in the 0-8 m depth bin, than the 8-16 m depth bin (Figure 4). Three burbot were captured in a sinking horizontal gill net that was set at 67 m.

Age, Size, and Relative Weight

Kokanee.—Scale analysis revealed that age-1 kokanee averaged 172 mm and weighed 43 g, age-2 kokanee averaged 236 mm and weighed 116g, and age-3 kokanee averaged 260mm and weighed 146 g (Table 3). Kokanee relative weight was consistently below the national standard across all sizes and averaged 80 (± 9 SD) (Figure 5).

The vast majority (95%) of kokanee greater than 245 mm were showing signs of sexual maturity (Figure 6). Carcass surveys in Harvey Creek indicated that the majority of age-2 and age-3 (Brood year ages 3 and 4) kokanee on the spawning grounds in 2002 were between 240 and 300 mm (McLellan 2003).

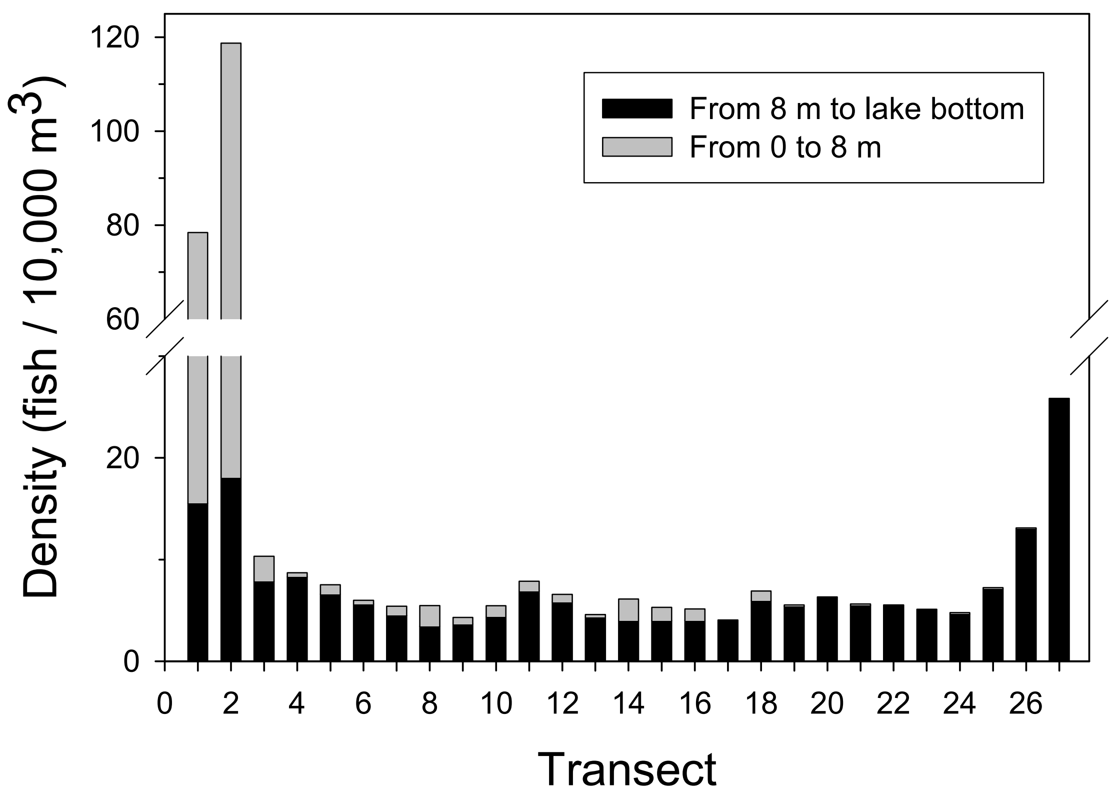

Figure 2. Density of target-tracked fish from a hydroacoustic survey of Sullivan Lake, WA in September of 2003. The horizontal transducer sampled fish between 1.5 and 8 m depth, whereas the vertical transducer observed fish from 8m to the bottom of the reservoir. Transect 1 began at the north end (near Outlet Ck) and transect 27 ended at the south end (near Harvey Ck).

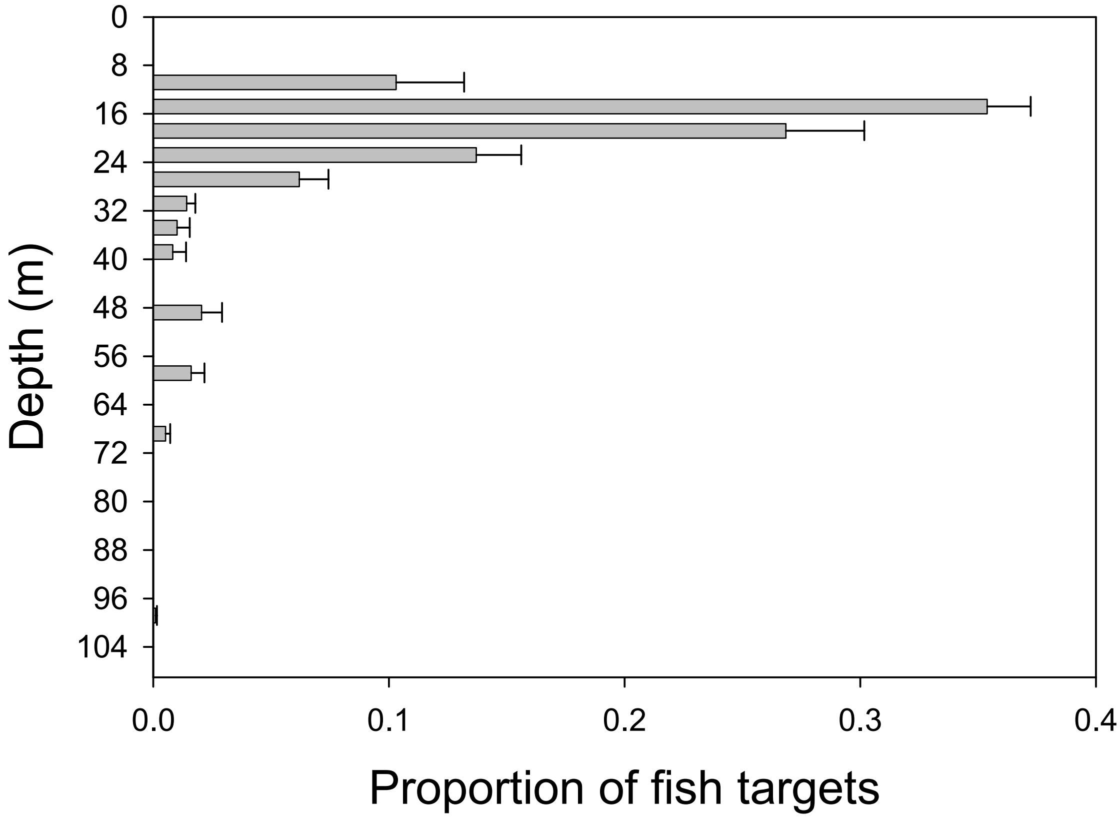

Figure 3. Vertical distribution of acoustically detected fish targets from the vertical transducer (from 8 m to the lake bottom) on Sullivan Lake, WA, September, 2003.

Table 1. Sample size (n), percent composition, and lengths of fish captured in offshore gill nets in Sullivan Lake, WA in September of 2003.

			Length (mm)		
Species	n	% composition	Mean	Minimum	Maximum
Burbot	5	8%	432	288	579
Cutthroat trout	8	12%	324	282	376
Kokanee	51	77%	219	165	286
Pygmy whitefish	1	2%	139	139	139
Redside shiner	1	2%	110	110	110
Total	66	100%			

Table 2. Catch per unit effort (CPUE) for all species of fish in various net types set in Sullivan Lake, WA in September of 2003. Suspended horizontals were stratified into 2 depth categories, those set deeper than 30 m below the surface and those set less than 30 m below the surface. Each unit of effort represented an overnight gill net set.

Net Type	Effort	Catch	CPUE
Floating Horizontal	4	11	2.75
Sinking Horizontal	4	6	1.50
Suspended Horizontal (> 30 m)	3	0	0
Suspended Horizontal (< 30 m)	11	20	1.82
Vertical	29	29	1.00

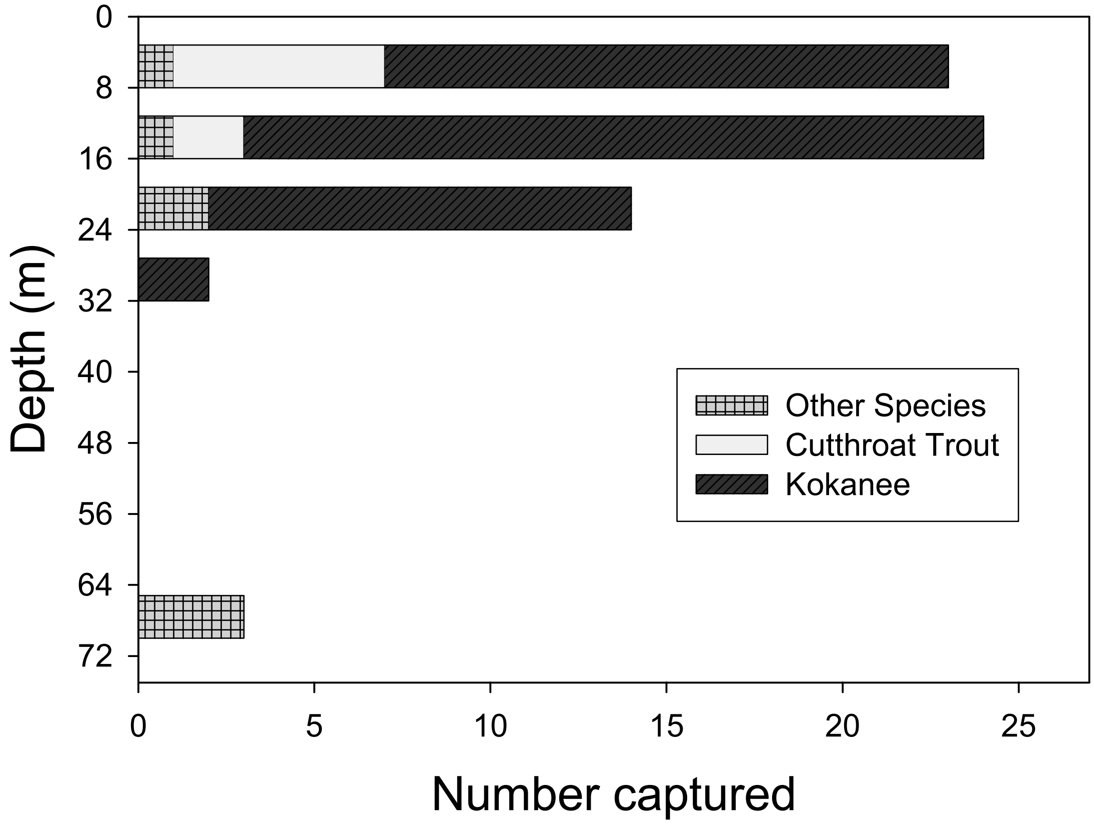

Figure 4. Vertical distribution of fish captured in offshore gill nets in Sullivan Lake, WA in September of 2003. Other species included burbot (n=5), pygmy whitefish (n=1), and redside shiner (n=1).

Table 3. Mean length and weight for specific age classes of fish captured in Sullivan Lake, WA in September of 2003. Age was determined by the number of annuli so brood year ages would be an additional year older.

			Total Length (mm)			Weight (g)
Species	Age	n	Mean	Minimum	Maximum	Mean
	2	4	300	284	311	296
Cutthroat trout	3	6	319	243	368	331
	4	3	367	345	381	466
	1	20	172	165	180	43
Kokanee	2	8	236	207	262	116
	3	15	260	239	274	146
Pygmy whitefish	2	1	139			18
Rainbow trout	3	1	373			504

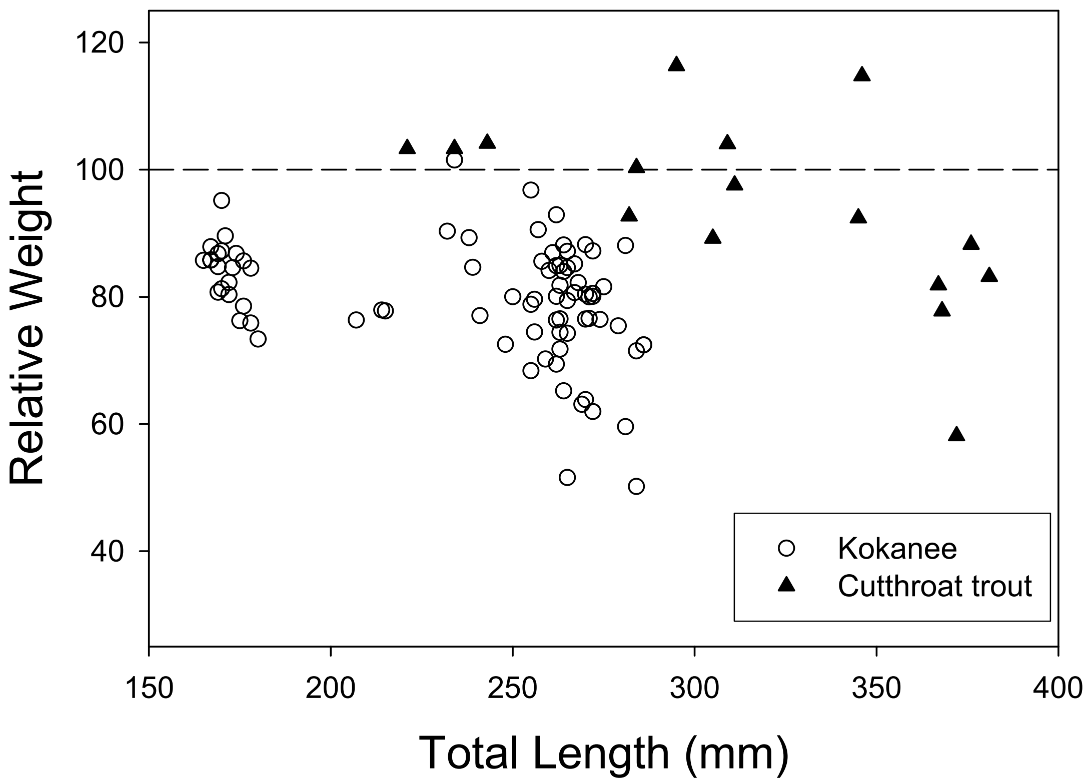

Figure 5. Relative weight of kokanee and cutthroat trout in Sullivan Lake, WA in September of 2003.

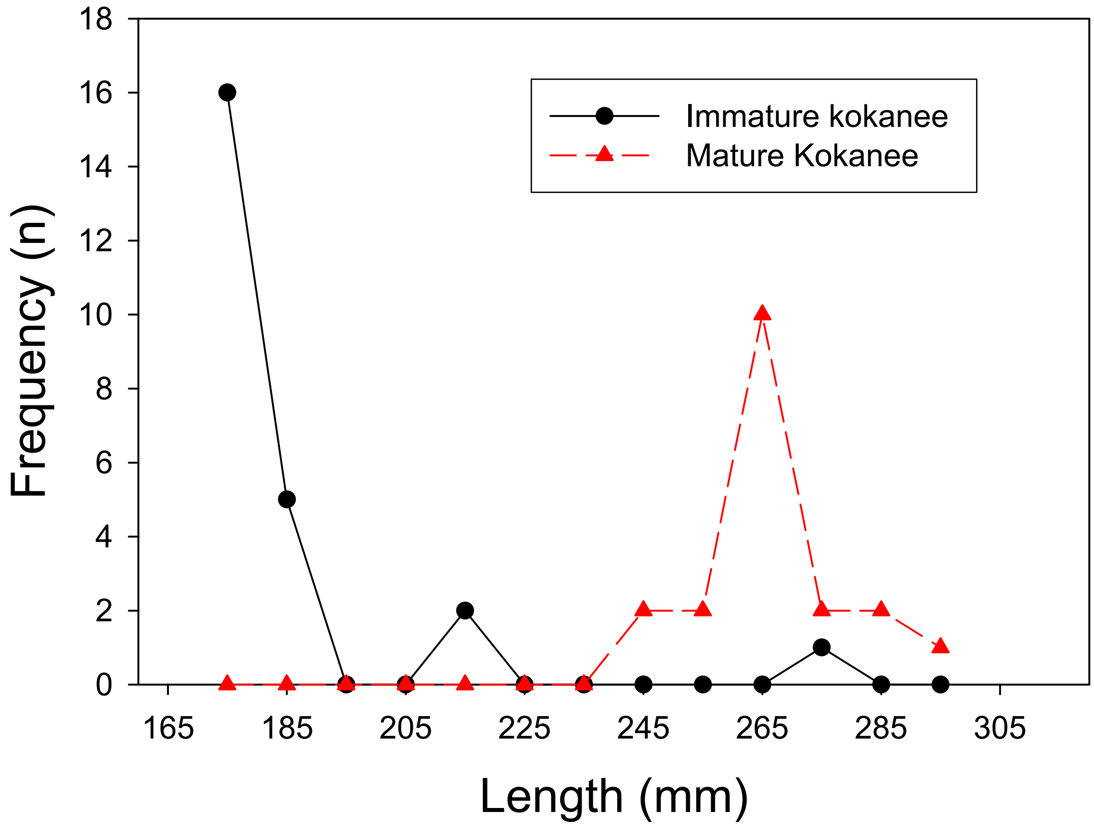

Figure 6. Lengthfrequency of sexually mature and immature kokanee from an offshore and nearshore gill net survey on Sullivan Lake, WA in September of 2003.

Cutthroat trout.—Scale analysis indicated that age 2, 3, and 4 cutthroat trout averaged 300, 319, 367 mm respectively (Table 3). However, sample sizes were quite small (3-6 per age class), increasing the probability of inaccurate results. Cutthroat trout less than 325 mm total length were generally near or above the national standard for relative weight, whereas larger individuals (> 350 mm TL) were generally below the national standard (Figure 5).

Limnetic Fish Abundance

Hydroacoustic density estimates were expanded to total lake volume resulting in a lake-wide abundance estimate of 228,667 (± 80,244 SE) fish with target strengths between –55 and –28 dB (~30-800 mm total length). Fifty-nine percent of the acoustic targets were too small to be verified by our gill net survey (< 150 mm). However, we assumed that the species composition from the gill net survey was a valid estimate of species composition for smaller targets in order to estimate the abundance of age-0 kokanee. Thirty-seven percent of the acoustic targets were in the size range (150-300 mm) of kokanee captured in the gill nets. We used the overall species composition for all size classes of kokanee to bias due to small sample sizes within certain size classes. We partitioned the acoustic targets into four size categories that corresponded to kokanee age-0 (103,281 ± 36,243 SE), age-1 (34,460 ± 12,093), age-2 (22,220 ± 7,798), and age-3 (10,030 ± 3,520) Table 4.

Discussion

This survey of the limnetic fish populations of Sullivan Lake revealed a high- density population of kokanee distributed primarily in and above the thermocline throughout all areas of the lake. The estimate of age-3 (BY age-4) kokanee (10,030) comported well with the Harvey Creek spawning escapement estimate (9,231), especially considering that the spawning escapement estimate could not quantify the loss due to predation and scavengers (McLellan 2005). We also estimated that there were strong year classes of age-0 and age-1 kokanee that should recruit to the fishery and the spawning grounds in future years.

The low relative weight of all kokanee and low total length-at-age of mature kokanee indicated that the population density was high enough that competition for food resources was impacting the growth rate (Rieman and Meyers 1992; Teuscher and Luecke 1996). The small mean size of *Daphnia pulex* in Sullivan Lake in 2003 also suggested that competition for food resources was influencing kokanee growth. The mean length of *Daphnia pulex* in Sullivan Lake was 0.78 mm (Nine *in prep.*). In lakes with high densities of planktivores the mean size of larger species of zooplankton, such as *Daphnia* spp., declines to below 1.0 mm (Brooks and Dodson 1965; Galbraith 1967; Post and McQueen 1987). Large *Daphnia* are selectively preyed upon and smaller zooplankters, such as *Bosmina* spp. and cyclopoid copepods, dominate the zooplankton species composition. Table 4. Abundance estimates for all acoustic fish targets and for specific age classes of kokanee in Sullivan Lake, WA in September of 2003.

Size Class (mm)	All Acoustic Targets 30-800	All Kokanee 30-300	Age-0 30-150	Age-1 150-200	Age-2 200-250	Age-3 250-300
% of Acoustic Targets	100%	97%	59%	20%	13%	6%
% Kokanee	NA	77%	77%	77%	77%	77%
Abundance	228,667	169,991	103,281	34,460	22,220	10,030
SE	80,244	59,653	36,243	12,093	7,798	3,520
Fish / ha	409	304	185	62	40	18

Cyclopoid copepods had the highest density and biomass during all sampling periods at all locations in Sullivan Lake in 2003 (Nine *in prep.*).

Rieman and Myers (1992) found that density dependent reductions in growth were more prominent in oligotrophic systems, such as Sullivan Lake. A lake with high densities of small fish has the potential to yield fewer fish to the fishery due to reduced catchability of the smaller fish (Rieman and Maiolie 1995). Rieman and Maiolie (1995) found that when density of adult kokanee exceeded 50 per hectare there was no corresponding increase in catch rate or yield in the fishery. Additionally, reduced length-at-age would reduce fecundity of mature females and the ability to form redds in larger substrates would be impacted, thereby reducing the productivity of the natural population. Our hydroacoustic assessment estimated a density of 58 age-2 and age-3 (BY 3 and 4) kokanee per hectare, putting the Sullivan Lake kokanee population in the range of the ideal trade-off between density and catchability.

Given the low relative weight of age-3 and age-4 cutthroat trout, it also appeared that food resources were limited for other species that typically have a diet less dependent upon zooplankton. Limited sampling by Nine (*in prep.*) indicted that the density and diversity of benthic macroinvertebrates were low in Sullivan Lake when compared to other Northwest lakes. There needs to be more investigation into the factors limiting cutthroat trout growth in Sullivan Lake.

We assumed equal probability of gill net capture between species; however, this assumption could have overestimated abundance, if a species was more vulnerable to the gill nets. For example, if kokanee were more active than cutthroat trout, but just as likely to be retained by the net once it was encountered, then kokanee abundance was overestimated while cutthroat trout abundance was underestimated. The gill nets only captured fish greater than 100 mm (most effective > 150 mm), and larger fish have greater capture probabilities in gill nets (Hamley 1975; Rudstam et al. 1984; Henderson and Wong 1991). We applied the species composition from all fish captured in the gill nets to all acoustic targets greater than –28 dB (~30 mm). If species composition of the smaller fish (<150 mm) was different, then our acoustic estimates would be biased for the smaller size classes. There were high densities of redside shiners < 150 mm in electrofishing surveys of Sullivan Lake (Nine in prep.). If redside shiners were present in the limnetic zone, then the abundance estimate for age 0 kokanee was overestimated.

Confirming targets of the smaller size classes would best be accomplished using trawling. Knowing the abundance of age 0 kokanee would improve run size predictions, calculating natural escapement numbers, and determining stocking needs if it is to be used as a brood source. We did not generate species-specific abundance estimates for fish species other than kokanee, because they were such a small proportion of the net catch.

The extremely high density of near surface fish targets in transects 1 and 2 increased the variance of the acoustic estimate (Figure 2). The coefficient of variation for the vertical transducer was considerably less (0.14) than with the horizontal transducer (0.64). However, it was necessary to combine these estimates due to the presence of kokanee in the 0-8 m depth bin from the gill net survey.
We could not determine the volume of water in the limnetic zone independently from the littoral zone. Mean density was extrapolated to lake-wide volume; therefore, we assumed that fish density in the littoral zone was equal to the limnetic zone for the species composition observed in limnetic gill nets. We recognize that species composition was different in the littoral zone and included many more species than we observed in the limnetic zone. If nearshore densities of kokanee were higher than offshore densities then we underestimated lake-wide abundance for kokanee; however, the relatively small volume of water in the littoral zone minimized the potential bias from this assumption.

The horizontal transducer could not differentiate target strength, so we could not determine the density of specific size classes for near-surface targets. We assumed that the size distribution of fish was the same from 1.5-8 m and from 8 m to the bottom. Similar mean lengths for each species and depth interval from the gill nets verified this assumption, with the possible exception of higher catches of cutthroat trout in the near surface depths which would have underestimated their contribution to the offshore abundance estimate.

This study evaluated the limnetic fish community of Sullivan Lake, as one aspect of a series of studies (by WDFW, KNRD, USFS, and EWU) with the goal of evaluating the limnology, fish resources, and species interactions in Sullivan Lake. We determined that adult kokanee densities were in a preferred range for angler catchability, but that relative weight was below average indicating that the observed fish densities were in competition for limiting resources. Future efforts may need to determine the carrying capacity of Sullivan Lake, based on the primary and secondary productivity results of the EWU studies (Beauchamp 1995; Baldwin et al. 2000). A bioenergetics analysis would allow managers to evaluate the growth versus density relationship and develop targets for recruitment of naturally produced fish versus the fry releases from those eggs removed from Harvey Creek spawning run.

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